

Bi-directional Reflectance and Other Radiation Parameters of
Cirrus from ER-2 Observations

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Passive and active remote sensing of cirrus were acquired from the ER-2 high altitude aircraft in the 1991 Cirrus Experiment. The observations include direct measurements of cirrus bi-directional reflectance from a new translinear scanning radiometer and also the previously employed measurements by lidar and visible-infrared imaging radiometers. For any cirrus radiative transfer application it is necessary to know the appropriate model for visible reflectance in relation to angle and also the optical thickness and infrared emissivity of the clouds. At a more complicated level, for remote sensing and overall cloud effects it is ultimately required to understand effects from multiple cloud layers, broken clouds and variable microphysics. Our overall data set from the scanning radiometers and lidar is intended to provide the necessary observations to investigate these problems.

Observations

The Electro-Optic Camera instrument is based on a commercially available silicon CCD array imager (Kodak KAF-1400). The device includes a six-position filter wheel which can be fitted with a combination of spectral filters and/or polarizing elements. The camera is mounted in the nose of the ER-2 and can tilt forward or aft up to 50 degrees. Radiometric images are acquired by the 1280x1025 array detector. With the nominal f/2.8 lens in place the total angular field of view for a single scene is 14.2 by 17.6 degrees. At full resolution the pixel size at ground altitude is about 5 m. When data is acquired the camera tilts at a steady linear rate to track a scene at a preset altitude. For the cirrus experiment the observation altitude was typically 9 km. During a scan images at the six filter positions are obtained at about a 10 degree angular separation.

The use of lidar and visible/infrared cross track scanning radiometric imagers in cloud experiments has been previously described (Spinhirne and Hart, 1990). For the cirrus experiment the ER-2 lidar incorporated an updated data system which permitted twice the previous pulse repetition rate and allowed operation over a full six hour flight. The visible/infrared

imager was an improved version of a Deadalus instrument as had been flown in the previous FIRE missions.

Analysis

The major difficulty in analyzing the cirrus bi-directional reflectance data is the inhomogeneity of the cirrus layers and underlying surfaces. In the initial attempt to analyze results we searched for scenes where observations were acquired over water for a dark uniform background and where cirrus existed as a single uniform layer. The lidar data defines the layered structure and height of the clouds. Since most of the cirrus experiment flights were over land and since most clouds are multi-layered no idealized case as given above were found. Several examples of cirrus over broken stratus with a water background were available. For these cases it was possible to determine the relation of the cloud reflectance as a function of view angle if individual cirrus parcels were identified and tracked from one image to subsequent images at other angles. Cirrus parcels were selected which were not contaminated by reflectance from the underlying broken stratus.

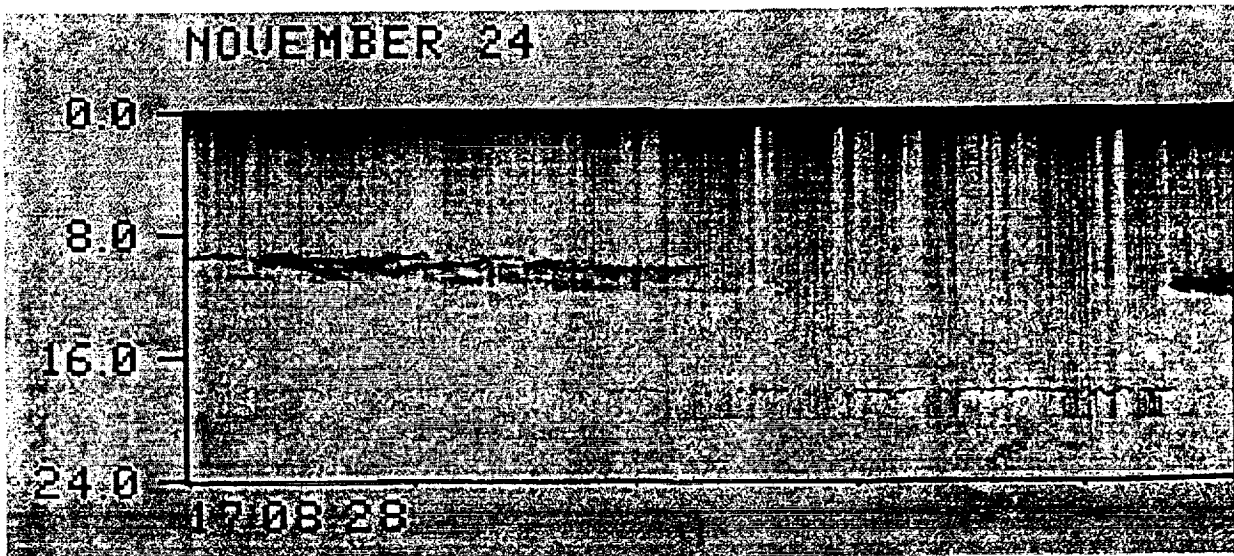


Fig. 1 Lidar data image corresponding to the EOC data for Fig 2. The vertical scale is height in kilometers from the aircraft altitude. Each horizontal tick is 2 minutes or about 24 km distance.

A case that was analyzed is from a flight on November 24, 1991 over the Gulf of Mexico. The lidar cloud structure cross section for the case is shown in Fig. 1. The two lower linear features are signals from a broken stratus deck and ocean surface. Fig. 2 gives the result for the bi-directional reflectance of the cirrus formation shown near the beginning of the data in Fig. 1. Result are shown for three small cloud areas and the overall image.

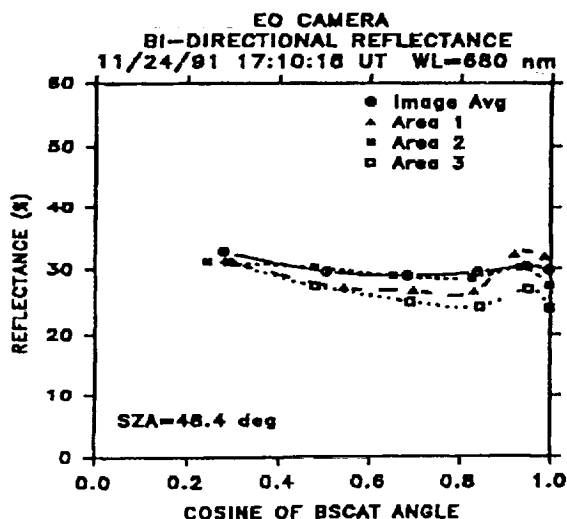


Fig. 2 Observed values of the angular dependence of a cloud scene during the 1991 cirrus experiment.

The measured reflectance function agrees with the modeled ice cloud better than for the functions calculated for water.

However even for area 1 the reflectance as a function of angle is flatter than for the calculated ice cloud curve. It is of interest to note that the scene image average with cirrus over broken status gives a much flatter function of reflectance versus angle than for either the water or ice models. For comparison, another measured angular reflection function is shown in Fig. 4. The scene of Fig. 4 is a marine stratus cloud acquired during an ASTEX flight. The measured function agrees well with the reflectance

For a comparison, modeled cloud reflection curves are given in Fig. 3. The values were modeled by discrete ordinate calculations (Nakajima, 1988). Phase functions for water and ice model cloud particle distributions were used. The water distribution assumed 10 μm spheres and the ice phase function was that of Takano and Liu (1989).

Area 1 of Fig. 2 is the region with the least probability to be contaminated by reflectance of the underlying stratus clouds.

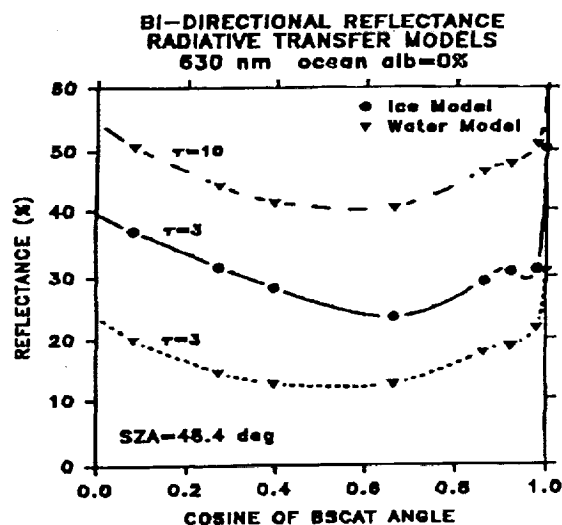


Fig. 3 Calculations of the angular reflection function for various cloud types.

function calculated for a water cloud of an optical thickness of approximately eight.

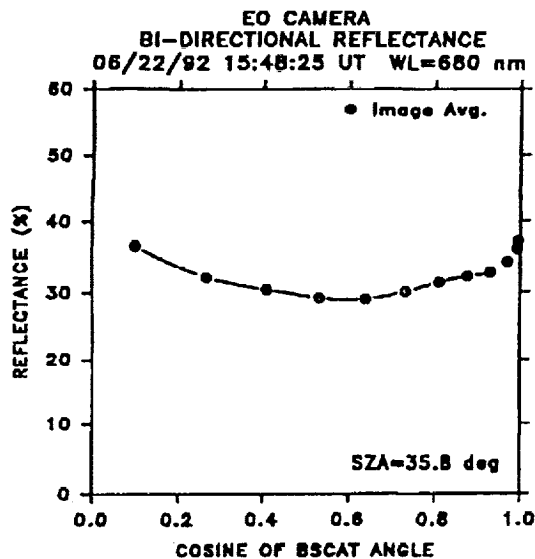


Fig. 4 Observation of the angular reflection function for a homogeneous marine stratus cloud.

The initial measurements from the EOC instrument indicate valid results. At present analysis algorithms are being automated in order that a large variety of cloud types may be investigated. In addition to data from the cirrus and ASTEX experiments, we now have a large set of measurements for tropical cirrus from the TOGA/COARE experiment. From lidar, spectral visible and infrared radiometer and flux measurements from the ER-2, it is thus possible to characterize cloud particle type and size, cloud optical thickness and emissivity.

When combined with the results from the new translinear scanning radiometer instrument, a comprehensive characterization of the dependence of angular reflection function and other radiation parameters on cloud type should be possible.

References

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